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Potential impacts of climate change on the distribution of *Subpsaltria yangi* (Hemiptera: Cicadidae), a rare cicada species in the Loess Plateau and adjacent areas in China

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Abstract: 【Aim】 Climate change is expected to continue to play a dominate role in causing habitat loss for many organisms over the next decades. Due to the vulnerability of endemic species, it is essential to predict the impact of climate change on the distribution of species with a high degree of endemism in order to conserve biodiversity. 【Methods】 The current and future habitat suitability of the endemic cicada *Subpsaltria yangi* in China, an evolutionarily and ecologically significant species of conservation concern in the Cicadoidea, was assessed using the Maxent model based on the current known distribution records of this species combined with the bioclimatic and topographic data of related areas. 【Results】 Our results showed that this rare species is strictly confined to the Loess Plateau and adjacent areas. Future predictions to the year 2050 showed a clear decrease in suitable area for *S. yangi*, even under a moderate climate change scenario. Annual mean temperature, minimum temperature of the coldest month, mean temperature of the coldest quarter and precipitation of the wettest month are all critical factors associated with the habitat distribution of this species. Existing areas should be protected from encroachment, and some areas such as Tianshui in Gansu Province and Yan'an in Shaanxi Province should be treated as the key protected areas for *S. yangi* in response to pending climate change. 【Conclusion】 The habitat suitability maps for *S. yangi* obtained in this study will provide useful information for discovering new populations, identifying top-priority survey sites, planning land management around existing populations and setting priorities to restore natural habitat for more effective conservation of this rare species.

Key words: *Subpsaltria yangi*; climate change; insect conservation; ecology; species distribution model; Loess Plateau

1 INTRODUCTION

Many factors, including land-use change, climatic change and human activities, may result in the shrinkage, degradation or total destruction of habitat for flora and fauna, although climatic change is considered likely to play the dominate role over the next decades (Dawson *et al*., 2011; Keith *et al*., 2014; Zhang *et al*., 2014). The Intergovernmental Panel on Climate Change (IPCC) estimates that temperature will increase 0.2℃ in each future decade; this underpins the importance of conserving biodiversity in the face of changing climatic conditions (IPCC, 2014a). This upward trend in temperature will have harmful consequences for biodiversity (Millennium Ecosystem Assessment, 2005). A large fraction of terrestrial species face increasing risk of extinction under projected climate changes during and beyond the 21st century (IPCC, 2014a). Therefore, predicting the impact of climate change on endemic and rare species is a key requisite to conserving biodiversity. The increasingly evolution-based species distribution models provide useful tools to tackle this issue in conservation biology under climate change (Guisan and Thuiller, 2005).

Species distribution models mainly use distribution data (presence or absence) on species and environmental data to algorithmically estimate species niches, and then project those niches onto the landscape, reflecting a species' habitat preferences in the form of a probable range (Guisan

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and Thuiller, 2005; Elith and Leathwick, 2009). In recent decades, species distribution models became an indispensable tool for predicting the potential distribution of a species and estimating the likely impact of future climate change (Thomas *et al.*, 2004; Peterson, 2006; Kumar and Stohlgren, 2009). Currently, typical species distribution models include BIOMOD (Thuiller, 2003), GARP (Stockwell and Peters, 1999), Maxent (Phillips *et al.*, 2004), BIOCLIM (Busby, 1991), DOMAIN (Carpenter *et al.*, 1993), GAM (Yee and Mitchell, 1991), GLM (Lehmann *et al.*, 2002), *etc.* Although most species distribution models need data on both the presence and absence of species for the model, the Maxent model can work with presence (or occurrence) data alone (Phillips *et al.*, 2006). In addition, Maxent can construct a satisfactory model with as low as five occurrence data for a species (Pearson *et al.*, 2007). Due to difficulty in obtaining reliable absence data, the Maxent model has been considered to be an efficient tool for unconcerned and rare species, and possesses high utility in planning conservation actions (Bosso *et al.*, 2013; Verovnik *et al.*, 2014; Cuevas-Yáñez *et al.*, 2015).

The cicada *Subpsaltria yangi* Chen was originally described in 1943. This is the only known species of the tribe Tibicininii in China, which has been placed in the subfamily Tettigadinae (Chen, 1943; Chou *et al.*, 1997; Hou *et al.*, 2017), but was removed recently to the subfamily Tibicininae (Marshell *et al.*, 2018). This cicada species is significant in that, besides males possessing timbal organs, it has stridulatory organs that are found in both sexes (Chen, 1943; Chou *et al.*, 1997; Luo and Wei, 2015a). The understanding of its acoustic communication based on special structures would provide important insights into the evolution of the acoustic communication system for this group of insects (Hou *et al.*, 2017). This species has been recorded as sporadically distributed in the center of Shaanxi Province, China, including Fengxian County, Zhouzhi County, Wugong County, Tongchuan City and Xianyang City (Chen, 1999); however, it has not been observed in these areas in recent decades and was thought to be extinct (Luo and Wei, 2015a). Fortunately, *S. yangi* was discovered in a survey of insect fauna of the Helan Mountains which is located at the border of Ningxia Hui Nationality Autonomous Region and Inner Mongolia Nationality Autonomous Region, China (Luo and Wei, 2015a). Furthermore, during our field investigations since 2011, a few more populations have been discovered from the Loess Plateau in Shaanxi, Shanxi and Gansu Provinces. These specimens were evoked and collected using our special acoustic playback method (Luo and Wei, 2015b, and unpublished data), and consequently, 31 distribution locations were obtained for *S. yangi* up to date (for details see below). These new discoveries of *S. yangi* provide useful information for the assessment of habitat conditions and conservation of this rare and little-known species. However, no studies have been conducted to perform a habitat evaluation or investigate the impact of climate change on the suitable habitat distribution of this species.

In this study, we utilized the Maxent model to study the current distribution of *S. yangi* and its response to current and future climate change. The objectives of this study are (1) to predict the potential geographical distribution of *S. yangi* and to evaluate the habitat suitability under the current climate scenario; (2) to determine which ecological factors may limit the species distribution; (3) to predict the potential habitat of *S. yangi* and to quantify the lost habitat area under two climate-warming scenarios; and (4) to advise the scientific community on key preferentially protected areas of *S. yangi* to better respond to the threat of climate change.

2 MATERIALS AND METHODS

2.1 Study area

According to currently known records and field surveys, *S. yangi* is an endemic species centered in Shaanxi Province. But our study area extends to neighbouring regions that possess a similar environment, a logical and reasonable strategy to confirm the potential distribution. The study area we selected was centred on Shaanxi Province and included the surrounding regions such as eastern Gansu Province, Ningxia Hui Autonomous Region, the southern Inner Mongolia Autonomous Region, Shanxi Province and Henan Province. This region is approximately between 40.6°N and 30.1°N and 114.8°E and 101.8°E (Fig. 1).

2.2 Occurrence data collection

Due to scant prior study and cursory historical records for *S. yangi*, there are no available occurrence data for the Maxent model. Therefore, the occurrence locations of *S. yangi* were completely based on our extensive filed surveys in Shaanxi Province and its surrounding area from early June to the middle of July each year (the high occurrence period of *S. yangi*) from 2014 to 2017. To ensure the availability of data and match the model, two adjacent populations must be more than 1 km away.

As a result, 31 occurrence locations were obtained to date (Fig. 1; Table 1). All location records were noted using a hand-held GPS (eTrex Vista H, GARMIN, China).

Fig. 1　Occurrence locality of *Subpsaltria yangi* in the Loess Plateau and adjacent areas in China
The basal map was obtained from the National Geomatics Center of China (http://ngcc.sbsm.gov.cn/).

Table 1　Occurrence points of *Subpsaltria yangi* based on field investigation in this study

Locality	Population no.	Longitude and latitude
Taibai, Shaanxi	1	107.650336°E, 34.150702°N
Hancheng, Shaanxi	1	110.435719°E, 35.525265°N
	2	110.439414°E, 35.521631°N
	3	110.437612°E, 35.523308°N
Tongchuan, Shaanxi	1	109.316248°E, 35.458709°N
	2	109.314562°E, 35.456654°N
	3	109.315851°E, 35.458508°N
Fengxiang, Shaanxi	1	107.400736°E, 34.521217°N
	2	107.400265°E, 34.521245°N
	3	107.401254°E, 34.522634°N
Yan'an, Shaanxi	1	109.518027°E, 37.175333°N
	2	109.522608°E, 37.175897°N
	3	109.519964°E, 37.175367°N
Luliang, Shanxi	1	110.712701°E, 37.126873°N
	2	110.713468°E, 37.125745°N
	3	110.712689°E, 37.126452°N
Yonghe, Shanxi	1	110.478749°E, 36.771982°N
	2	110.478979°E, 36.771594°N
	3	110.478931°E, 36.771999°N
Jixian, Shanxi	1	110.725603°E, 36.165543°N
	2	110.726902°E, 36.166171°N
	3	110.727079°E, 36.165911°N
Xiangning, Shanxi	1	110.702645°E, 35.767519°N
	2	110.701326°E, 35.768276°N
	3	110.700886°E, 35.767257°N
Helan Mountains, Ningxia	1	105.931145°E, 38.563952°N
	2	105.931642°E, 38.563321°N
	3	105.936452°E, 38.566422°N
Pingliang, Gansu	1	106.665131°E, 35.543061°N
	2	106.665482°E, 35.543651°N
	3	106.664862°E, 35.543621°N

2.3　Environmental variables

The WorldClim database provides a total of 19 bioclimatic variables, which discriminate at approximately 1 km^2 resolution (Hijmans *et al.*, 2005; http://www.worldclim.org). The WorldClim data are derived from measurements of altitude, temperature and rainfall from weather stations worldwide during 1950 – 2000. In this research, the Pearson correlation coefficient $r \leqslant \pm 0.85$ is used as a cut-off threshold to determine the exclusion of highly correlated variables (Yi *et al.*, 2016). According to the correlation analysis of 19 bioclimatic variables, eight bioclimatic variables (Bio 1, Bio 6, Bio 8, Bio 11, Bio 12, Bio 13, Bio 16, and Bio 17) were reserved (see Table 2 for detailed information). All variables were processed using ArcMap software (version 10.2, ESRI, USA).

The Digital Elevation Model (DEM) data were derived from the "China Western Environment and Ecology Science Data Centre" (http://westdc.westgis.ac.cn) with a spatial resolution of 1 km^2. The ArcMap software was used to deal with these DEM data to obtain topographic variables including elevation, aspect and slope, which have the same spatial resolution as climate variables.

For the future model prediction, the mid-century projected time period was selected to coincide with China's newly released development plan "China in 2050 Low-carbon Development Path" (Research Group of Energy Research Institute of National Development and Reform Commission, 2009).

Table 2 Bioclimatic and topographic variables used for modelling the suitable distribution of *Subpsaltria yangi* in this study

Data source	Category	Variables	Abbreviation	Unit
WestDC	Topographic	Elevation	Elevation	m
		Aspect	Aspect	degree
		Slope	Slope	degree
WorldClim	Bioclimatic	Annual mean temperature	Bio 1	℃
		Minimum temperature of the coldest month	Bio 6	℃
		Mean temperature of the wettest quarter	Bio 8	℃
		Mean temperature of the coldest quarter	Bio 11	℃
		Annual precipitation	Bio 12	mm
		Precipitation of the wettest month	Bio 13	mm
		Precipitation of the wettest quarter	Bio 16	mm
		Precipitation of the driest quarter	Bio 17	mm

In the IPCC Fifth Report (IPCC, 2014b), four Representative Concentration Pathways (*i. e.*, RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5) were coded according to a possible range of radiative forcing values in the year 2100 relative to preindustrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively). According to China's low carbon emission policy (Liu *et al.*, 2015), only the moderate climate change scenario (RCP 4.5) projection was considered in this study. Here two different future global climate models were used for projection to 2050, namely the Geophysical Fluid Dynamics Laboratory Climate Model Version 3 (GFDL-CM3) developed by the National Oceanic and Atmospheric Administration (NOAA) and the Norwegian Earth System Model 1-Medium Resolution (NorESM1-M) developed by the Norwegian Climate Centre. These two future climate models are part of the IPPC5 climate projections based on global climate models (GCMs), and both models provide a high spatial resolution that can result in as high as possible accuracy in prediction. Both models were downloaded from WorldClim (http://www.worldclim.org) and selected with 30 s (approximately 1 km^2) resolution.

2.4 Maxent model

The application of Maxent in species habitat suitability prediction can be expressed as follows: if no information about a species' local ecological conditions is available, the most reasonable prediction is that the probabilities that the area is either suitable or not for the species are both 0.5. Any data that indicate a species is present within a set of local ecological conditions is information that will reduce the uncertainty of a Maxent model. The more information there is, the more uncertainty is reduced. The Maxent approach is to establish a model with maximum entropy in accordance with known knowledge (Phillips *et al.*, 2006; Phillips and Dudík, 2008). In the setting of Maxent of this study, the logistic output format was checked to generate response curves and jackknife results. The following options were set: random test percentage 20% (percentage of records to be randomly set aside as test points); write plot data; random seed; regularization multiplier (fixed at 1); 10 000 maximum number of background points; 1 000 maximum iterations; and, finally 15 replicate effects with bootstrap replicated run type.

Area under the curve (AUC) of a receiver operating characteristic (ROC) plot was used to measure model performance (Fielding and Bell, 2002). The larger the AUC is, the better the model performance is. In general, the AUC is between 0.5 and 1. An AUC < 0.5 indicates that the model performs worse than chance and rarely occurs in reality. An AUC of 0.5 represents pure guessing. Model performance is divided into five levels: failing (0.5-0.6), poor (0.6-0.7), fair (0.7-0.8), good (0.8-0.9) and excellent (0.9-1) (Swets, 1988). In this study, the calculated ROC shows that the AUC was high, with the mean value of 0.971 for training data and 0.966 for the test data, which indicate an excellent predictive ability. The AUC standard deviation with the low value of 0.001 shows that there is no sign of overfitting around the presence data.

After running 15 replicates, a single average model was output, which provided the probability of occurrence (PO) according to a 0-1 scale. Based on the likelihood ranges of the assessed PO in the IPCC Fifth Assessment Report (IPCC, 2014b; Zheng *et al.*, 2016), the suitability of habitat was categorized as four classes: (1) highly suitable, 1.0 > PO > 0.90; (2) moderately suitable, 0.90 > PO > 0.66; (3) marginally suitable, 0.66 > PO >

0.33; and (4) unsuitable, 0.33 > PO > 0. Habitat mapping of these classes for *S. yangi* was performed using ArcMap software.

3 RESULTS

3.1 Potential distribution and habitat of *S. yangi* under current climate conditions

Based on the currently known presence of *S. yangi* and bioclimatic and topographic variables, the model identified substantially uninterrupted areas of geographic distribution for *S. yangi* (Fig. 2). The suitable habitat (PO > 0.33) of *S. yangi* is predicted in eastern Gansu Province, middle and southern Ningxia Hui Autonomous Region, Shaanxi Province, the intermountain basin of Shanxi Province and northwestern Henan Province. All of the above predicted suitable habitats connect with neighbouring ones forming a whole large region located in the Loess Plateau. Within the suitable habitat of *S. yangi* modelled by Maxent, we detected some areas that are characterised by moderate presence likelihood (0.90 > PO > 0.66) or high presence likelihood (PO > 0.90); however, no distribution records for this species were found in some areas, *e.g.*, Tianshui City, Qingyang City and northeast Longnan City in Gansu Province (Fig. 2). We also detected areas in Taiyuan City, Shanxi Province and its surrounding area with a high probability of occurrence (PO > 0.90), but again this species has not been found in either location.

3.2 Analysis of key environmental variables

The results of the jackknife test of the variables' contribution showed that the model achieved a 2.6006 regularised training gain value, indicating a good fit to presence data (Fig. 3). Bio 11 (mean temperature of the coldest quarter) provided a very high gain (> 1.2) when used in isolation, indicating that Bio 11 contained more useful information by itself than did other variables. Bio 1 (annual mean temperature), Bio 6 (minimum temperature of the coldest month) and Bio 13 (precipitation of the wettest month) provided a high gain (> 0.4) when used in isolation. Bio 12 (annual precipitation), Bio 16 (precipitation of the wettest quarter) and elevation had a moderate gain (> 0.2) when used independently. Other variables, including aspect, Bio 8 (mean temperature of the wettest quarter), Bio 17 (precipitation of the driest quarter) and slope, had low gains (< 0.2) when used in isolation, indicating that they did not contain much more information by themselves than did other variables.

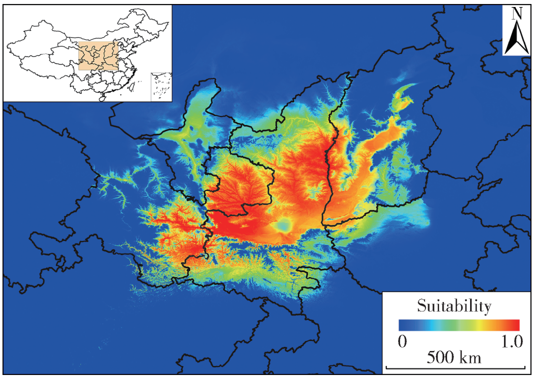

Fig. 2 Distribution of potential habitats for *Subpsaltria yangi* based on parameters fitting current locality records in the Loess Plateau and adjacent areas in China

The colour indicates habitat suitability under current climatic conditions. The basal map was obtained from the National Geomatics Center of China (http://ngcc.sbsm.gov.cn/).

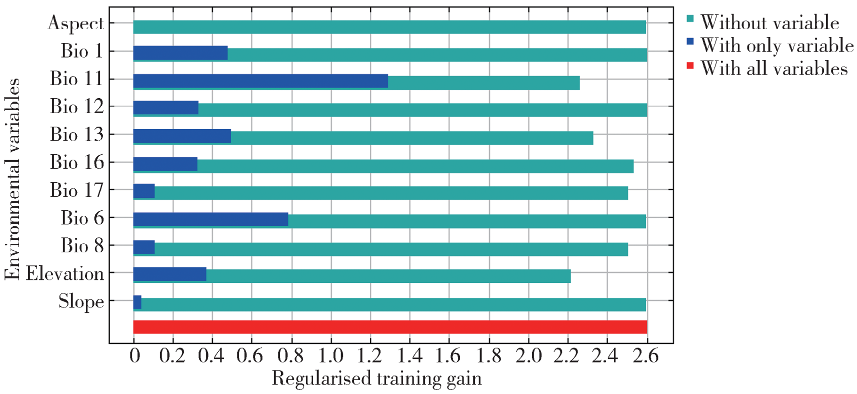

Fig. 3 The jackknife test for evaluating the relative importance of bioclimatic and topographic variables for *Subpsaltria yangi*

The dark blue color represents the gain of each variable, and the red color represents the gain of all variables.

According to the response curves (Fig. 4), all the 11 variables have a sensitive impact on habitat suitability with variables changing within a certain range, except for the variable aspect. The topographical variable elevation of response curves shows a suitable elevation for *S. yangi* ranging from

260 to 2 100 m, and habitat suitability becomes unsuitable (PO $<$ 0.33) where the elevation is over 2 100 m. This model predicts a decreasing habitat suitability of *S. yangi* with increasing slope, and it becomes unsuitable where the slope is over 9 degrees. Furthermore, the model predicts little sensitivity between aspect and probability of occurrence of *S. yangi*, indicating that aspect has no restrictive impact on this cicada species.

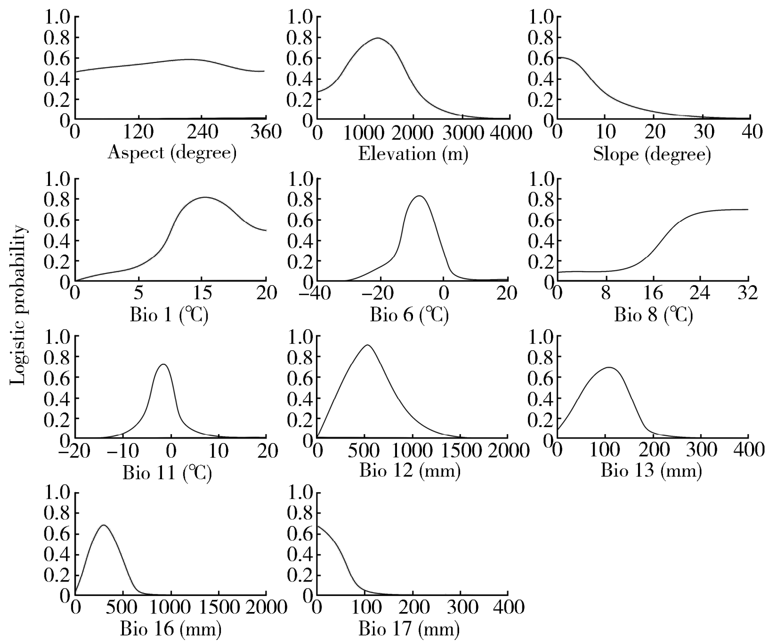

Fig. 4 Relationships between bioclimatic and topographic variables and the logistic probability of presence of *Subpsaltria yangi*
X-axis shows the value of variable; *Y*-axis shows the value of logistic probability of presence.

The highest logistic probability of occurrence appears when the Bio 11 is 0℃. Other climate variables were also found to contribute when modelling the distribution of *S. yangi*. Normally, in areas where there is a suitable habitat for *S. yangi*, Bio 1 is higher than 7.6℃; Bio 6 ranges from 14 to 0℃; Bio 12 ranges from 130 to 890 mm; Bio 13 ranges from 40 to 176 mm; Bio 16 ranges from 130 to 510 mm; Bio 8 is higher than 12℃; and Bio 17 is lower than 70 mm.

3.3 Habitat of *S. yangi* under climate change

With regard to future suitable habitat of *S. yangi*, modelling suggests that its habitat distribution will shrink in suitable area, and that the suitable level will decrease under the moderate climate change scenario (Figs. 5, 6).

Using GFDL-CM3 data under the RCP4.5 scenario projected to the year 2050, the predicted suitable habitat for this species remains inside its current distribution, and the area of highly suitable habitat predicted will shrink to that smaller area clearly surrounding the current highly suitable habitat calculated by this model, especially in the northeast region of Gansu Province (Fig. 5: B). Compared with the current habitat suitability classes, the percentages of total, marginally, moderately and highly suitable habitats in 2050 under the GFDL-CM3 model will decrease by 36.8% (155 707 km^2), 34.5% (87 992 km^2), 34.3% (48 087 km^2) and 70.6% (19 628 km^2), respectively (Fig. 6).

Using NorESM1-M data under the RCP4.5 scenario for the year 2050, a larger area of current habitat for this species will be unsuitable to inhabit than that was predicted using the GFDL-CM3 climate model. The area of highly suitable habitat predicted using NorESM1-M data will remain larger than that predicted using the GFDL-CM3 climate model under the RCP4.5 scenario (Fig. 5: C). The areas of total, marginally, moderately and highly suitable habitats are predicted to decline by 48.1% (203 631 km^2), 41.8% (106 826 km^2), 56.3% (78 979 km^2) and 64.1% (17 825 km^2), respectively (Fig. 6).

4 DISCUSSION

We have succeeded in developing a model which can detect a set of variables that, on a large spatial scale, defines a definite geographic distribution for the cicada *S. yangi*. It will provide guidance in the studied regions from a conservation point of view. In general, the models with AUC $>$ 0.75

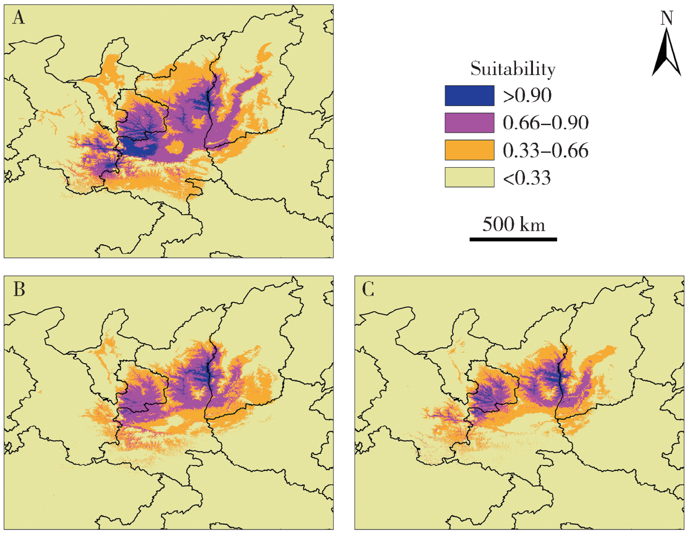

Fig. 5　Current and predicted future habitat distributions in 2050 under different climate scenarios for *Subpsaltria yangi* in the Loess Plateau and adjacent areas in China

A: Current distribution; B: GFDL-CM3 under RCP4.5 scenario; C: NorESM1-M under RCP4.5 scenario. The basal map was obtained from the National Geomatics Center of China (http://ngcc.sbsm.gov.cn/).

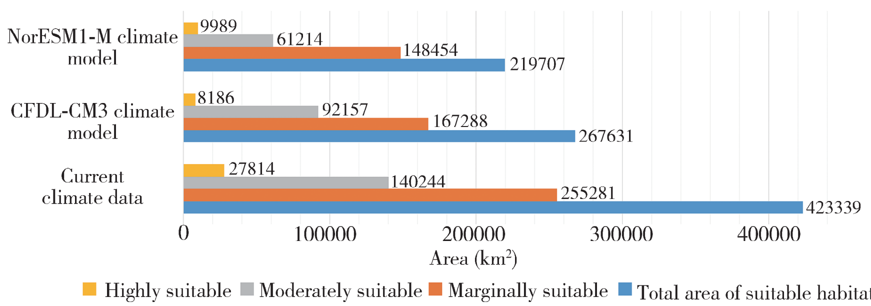

Fig. 6　The areas (km^2) of different habitat suitability classes under two climate-change scenarios and current condition for *Subpsaltria yangi*

are regarded as reliable and in our case, the model's AUC equals to 0.971 ± 0.001, demonstrating a high level of predictive capacity. Over 90.3% of collection records from our investigation were within the highly or moderately suitable zones (PO > 0.6) using this model, indicating that the habitat suitability of *S. yangi* predicted for the current scenario agrees strongly with ground observations. This indicates that the performance of this model is excellent and credible. Our results confirm that this rare species is strictly confined to the Loess Plateau and adjacent areas, and potential habitat with high PO will provide strong guidance in setting the priority survey site in the future.

The range of high quality suitable habitat for *S. yangi* predicted by our model is optimistic. As an example, there is a definite distribution record of *S. yangi* in Yangling, Shaanxi Province (Chou *et al*., 1997), where the Maxent model also predicted a high suitability for this species (PO > 0.90); but no individuals of this cicada were found during field investigations in recent decades. The same situation was also found in Fengxian, Shaanxi Province. Beyond the climate change that has occurred in the past decades, non-natural factors must also be involved. One main reason leading to local extinction of *S. yangi* might be attributed to the intensive agricultural activities resulting in habitat destruction, as the major land cover changed from forest and grassland to farmland since the late 1980s to 2000, with the ecological quality transformed from high grade to low grade (Zhou *et al*., 2016). Simultaneously, a large number of forested areas in the flat valleys and gentle slopes were reclaimed for cultivation because of increasing population (Zhao *et al*., 2013). Therefore, land transformation should also be a contributing factor which affects the distribution of *S. yangi*. In particular, this situation is even more pronounced for rare insects. For example, habitat changed by human (*e. g.*, felling, the under-story's reclamation) may make more individuals of the endangered butterfly *Teinopalpus aureus* fail to live, and then threaten the butterfly population, or even lead to the extinction of local

population (Zeng *et al.*, 2012). However, lack of quantifiable data was the reason for the absence of such data involved in our present study, which should be pursued in future work. Besides the impact of destruction of natural habitat resulting from agricultural activities, the phonotaxis of *S. yangi* males also makes this species susceptible to the negative impacts of anthropogenic sounds, which may affect mating activity of this species (Hou *et al.*, 2017). This habit might affect the fertilization success of *S. yangi* and contribute, together with the impact of habitat destruction from agricultural activities, to the extirpation or local extinction of this species.

Climate is often thought to be the predominant range-determining mechanism at large spatial scales (Blach-Overgaard *et al.*, 2010). These predictions by Maxent indicate that within a short time-scale through to the middle of the 21st century, climate change will cause a great risk of habitat loss for *S. yangi*. This model shows the habitat that is suitable under the current climatic conditions will become unsuitable in the future, resulting in local extinction (Fig. 6). Similar results have been reported by other experts or institutes that modelled climate impacts for different kinds of plant and animal species (*e. g.*, Delean *et al.*, 2013; Zhang *et al.*, 2014; Zheng *et al.*, 2016; Cheng and Bonebrake, 2017). These studies also revealed negative impacts of future climate change on both the range and habitat suitability of related species. Under two different future climate projections, highly suitable habitat for *S. yangi* in Pingliang, Gansu Province and Yan′an, Shaanxi Province exhibits remarkable response capacity to threats of climate change in the future. In these two regions, the habitat in Yan′an maintains highly suitable conditions (PO > 0.90), and that of Pingliang maintains moderately suitable parameters (PO > 0.66) (Fig. 5: B, C). These regions should be treated as the key protected areas or sanctuaries for *S. yangi* in response to the threat of habitat loss under future climate change in 2050. The response curves (Fig. 4) in our study show the quantitative relationships between environmental variables and logistic probability of occurrence (PO), and they deepen our understanding of the ecological niche inhabited by this species. In our work, we found that the PO of *S. yangi* presented a remarkable sensitivity to the impact of environmental variables (Fig. 4). One apparent inconsistency is that we obtained some samples of *S. yangi* from highlands and steep hills where the slope is beyond the limits calculated by Maxent. Slope data extracted from Digital Elevation Model may be too coarse to accurately simulate the real topographic conditions. The jackknife test shows Bio 1 (annual mean temperature), Bio 6 (minimum temperature of the coldest month), Bio 11 (mean temperature of the coldest quarter) and Bio 16 (precipitation of the wettest quarter) are the critical factors associated with the habitat suitability of *S. yangi*, demonstrating that they contain much more useful information than other variables. These results provide a narrower focus on understanding the ecological niche of this rare species.

A multitude of other factors may also determine the distribution of *S. yangi*, besides the topographic and environmental variables used in this research. The biological interactions (competition, predation, *etc.*), biological characteristics (host plant distribution, migration ability, *etc.*) of this species, as well as human activities, cannot be neglected. Our results might have been even closer to the actual distribution if some of these elements could have been reasonably employed as supplementary data within the model.

People usually have widespread prejudice against insects when choosing a species to protect. The fact that most insects are small and inconspicuous means that they are often ignored or dismissed (Kogan and Lattin, 1993). While most attention has focused upon the larger, showier species and their threatened states, others have recognized that literally tens of thousands of insects and other arthropod species are also at risk (Pimentel *et al.*, 1992; Wilson *et al.*, 1992). In the red list of threatened species published by the IUCN in 2008, there were 1 259 records of threatened and extinct insect species, which account for just 0.09% of the known insect species (IUCN, 2008). There are approximately over 88 000 insect species recorded in China, with only 120 genera and 110 species listed in the relevant protection regulations (Yu, 2004). The cicada *S. yangi* is not protected by any legislation, although Chen (1999) proposed that it is a rare and precious species. Through both our long-time field investigations and existing records, we confirmed that this rare species has a high degree of endemism, mainly strictly distributed in the Loess Plateau. Previous known records and our recent field investigations indicate that the habitat of *S. yangi* has been severely affected by the effect of human activities, and will further decrease in the immediate future due to climate change. Therefore, it is urgent that we pay more attention to this rare animal and formulate

corresponding conservation strategies. The potential habitat distribution map of *S. yangi* in our study provides new information for discovering new populations, identifying top-priority survey sites, planning land management around existing populations, and setting priorities to restore the natural habitat for more effective conservation of this rare species and other species which are endemic to the Loess Plateau. With the information provided here, we hope to trigger further research on both the distribution and ecology of this cicada species of conservation concern.

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气候变化对黄土高原及邻近地区稀有种枯蝉分布的潜在影响

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摘要:【目的】未来数十年的气候变化预计会是造成很多物种生境丧失的一个重要因素。对适应能力相对脆弱的地方性物种,预测气候变化对其生境的影响将对生物多样性保护具有重要意义。【方法】本文基于最大熵模型,对珍稀蝉科中国特有种枯蝉 *Subpsaltria yangi* 在当前和未来气候条件下的生境适宜度进行了评估。【结果】结果表明,枯蝉主要局限分布于黄土高原及邻近地区。预计至2050年,即使在温和的气候变化情景下,枯蝉的生境面积也会明显减少。影响枯蝉栖息地分布的关键因素为年平均气温、最冷月的最低气温、最冷季的平均气温和最潮湿月份的降水量。枯蝉现存种群栖息地应当受到保护,甘肃天水和陕西延安地区应作为枯蝉分布的核心区予以保护,以应对气候变化对其生境带来的影响。【结论】本研究获得的枯蝉适宜生境分布图可以为该稀有物种的新种群发现、现生种群分布地土地规划管理以及有效的自然保护区设立提供重要信息。

关键词: 枯蝉; 气候变化; 昆虫保护; 生态学; 物种分布模型; 黄土高原

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